



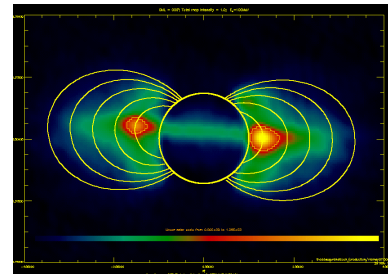
Earth

PHOTO: NASA/NOAA



Jupiter

PHOTO: NASA/JPL



False Color Image of Jupiter's
Synchrotron Radiation, data collected
by the VLA Image: NRAO/VLA

Rotation – Earth, Jupiter and Jupiter's Synchrotron Emission

Background Information for Teachers

This lesson set includes three activities, beginning with the visible rotation of Earth and then looking at the visible rotation of Jupiter and some indirect evidence of its rotation, specifically data on the [synchrotron emission](#) from Jupiter's magnetosphere. The beginning activity may be more appropriate for the younger audience. High school teachers may choose to discuss Part One briefly and move on to the comparative planetology in Parts Two and Three. As the lessons progress from Part One to Part Three, the level of challenge in the material increases.

Jupiter's magnetosphere is very large. If the magnetosphere of Jupiter could be seen from Earth, "it would cover an area in the sky sixteen times larger than the full moon" (Kaufmann, 1996). When charged particles are trapped within a magnetic field like the one surrounding Jupiter, they move around the magnetic lines of force in a path with the shape of a helix, rapidly circling the field lines as they move along them. In Jupiter's magnetosphere, many of these particles are moving very fast, near the speed of light. This helical motion of rapidly moving charged particles causes them to emit energy in the form of radio waves called synchrotron radiation. Collectively, the particles form belts around the planet, much like the Van Allen radiation belts around Earth. (Note that the "radiation" in "radiation belts" consists of subatomic particles, while the "radiation" in "synchrotron radiation" consists of radio waves.) Jupiter's radiation belts resemble a donut (toroidal) shape that surrounds the planet. The synchrotron radiation they produce is, by definition, non-thermal, meaning that it is not created by processes related to heat and temperature. The false color image you see in the video on either side of Jupiter represents the strength of the synchrotron emission (or the [radio brightness](#)) at the time the observation was made with the [Very Large Array](#) (VLA) collection of radio telescopes. Since the synchrotron radiation is produced by the particles in the radiation belt, the view resembles a cross-section of the belts, as if you had cut the donut in half and set the planet in the middle.

Jupiter's rotational axis and its magnetic pole are offset from one another by about ten degrees (this occurs for Earth also, and the offset is between 11 and 12 degrees), causing a wobble in the radiation belts as the magnetosphere rotates. As Jupiter's



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wobbling magnetic field, carrying the radiation belts with it, faces more toward Earth and then away from Earth in its rotation (somewhat like a plate spinning on a tabletop), the radio brightness of the synchrotron emission appears to brighten and dim.

Using the spinning plate analogy, when the plate is near the end of its spin, you can see it edge-on and then surface of the plate as an elongated oval, then the edge-on again etceteras. Jupiter's radiation belts present this changing aspect with each ~ ten hour rotation. This occurs because the synchrotron radiation produced by each particle is emitted mostly in the direction the particle is moving, like headlights on a car. As the particles circle around the field lines, they emit much more radiation perpendicular to the field lines than they do along the lines. Picture a small car with its lights on driving around the edge of the wobbling plate. You would see the most light when the car is driving toward you at the right or left edges of the plate. As Jupiter's rotation wobbles the magnetic field around, the total radiation we see from all the particles varies, getting brighter when we're looking at the field from the side (perpendicular) and getting dimmer when the field is tilting toward us or away from us. When the tilt is to the left or right, a lot of the "headlights" are aimed at us (like the edge-on plate), and when the field is tilted toward (or away) from us, most of the "headlights" are aimed too low (or too high) for us to see them as well (like the elongated oval plate).

Students will understand that:

- Earth and other planets rotate
- Data provides visual evidence for rotation for Earth and other planets
- Scientists can detect rotation of Jupiter by using [synchrotron radiation](#) data from the [Very Large Array](#) and other ground-based radio antennae

Resources/Materials needed:

- Rotating Earth Movie **or** a globe in place of the Rotating Earth Movie
- Jupiter Rotation Movie
- Jupiter Synchrotron Rotation Movie

This lesson set is applicable to Mid-Continent Research for Education and Learning (McREL) Science Education Standards as outlined on pages 15 - 16. Each standard is potentially applicable wholly or partially, depending upon implementation strategies in individual classrooms.

Teacher Notes on the Activities:

Part One: Earth

Rotating Earth Movie and pages 6 and 7 of this lesson

Students will need a globe or an animation of Earth rotating. Beginning at 0° latitude and 32° East longitude (Northwestern edge of Lake Victoria on the continent of Africa), have the students record what they see every 45° of longitude (at 0° latitude), land or



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water. There will be 8 recordings in a particular pattern that repeats. Have them sample two to three complete rotations so that the pattern will be evident. The worksheet allows for 16 observations.

If you are using the Earth Rotation video, one full rotation occurs every 8 seconds. Have the students record a land or water reading every second. This works nicely if you have the ability to project the image on a large screen. It helps to leave the computer cursor on the screen along the equator so that the students have a point of reference. You can start and stop the QuickTime® video easily by clicking the mouse. Position the cursor on the starting location. Double click to start the rotation motion. Single click to stop it. With a little practice you will be able to start and stop the movie easily. By using the timer, you can stop the movie when the clock changes seconds to let the students make their recordings.

Part Two: Jupiter

Rotating Jupiter movie and page 8 of this lesson

Show the Jupiter rotation movie with the clock running in the bottom right-hand corner. Ask students to select an easily identifiable feature of Jupiter's atmosphere and time how long it takes for the planet to make a full rotation in seconds. Do all parts of the atmosphere appear to rotate at the same rate? In the same manner?

Please note that Jupiter's rotation period is a little less than ten hours and varies slightly from the equator to the poles. This may or may not be apparent to the students, depending on how they are timing and/or observing. If they can track two features at once, one near the equator and another near the poles, it will be evident. For the first 11 seconds, the animation is roughly one hour of rotation per one second of animation. After the first 11 seconds the video slows down to show features more clearly and is no longer in this actual time to video ratio. The view after 11 seconds is a series of images of the Great Red spot and nearby features. It plays as if taken by a geosynchronous satellite.

Part Three: Jupiter's Synchrotron Emission

Rotating Jupiter and Synchrotron Emission and pages 9 -14 of this lesson

Show students the Jupiter Synchrotron Rotation video. This animation shows a false color image of the [synchrotron emission](#) ([flux density](#) or [radio brightness](#)) around Jupiter, with the planet Jupiter superimposed. Students should note how the intensity of the emission seems to change as the planet rotates and wobbles.

The line at the bottom of the movie animation represents the flux density of the radio energy collected from Jupiter, as a whole, at any given time in the rotation of Jupiter. The unit of measurement in this case is the Jansky. Students should note the data points' positions on the graph as the planet and its radiation belt (donut) wobble toward

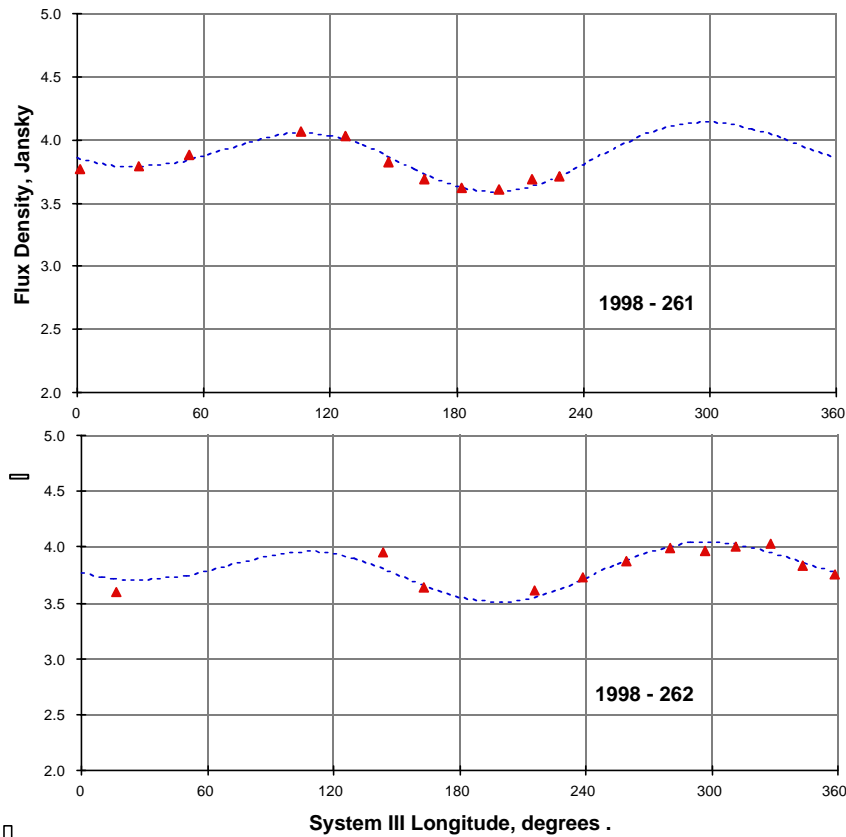


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and away from Earth. An example of this type of data graph with appropriate labels is shown below.

Jupiter Radiation Belt Emission Ten Hour Rotation Cycle



Using the mouse, you can stop and start the movie. A double click on the movie image itself starts it. A single click stops it. The clock in the upper left-hand corner of the movie panel indicates hours. One rotation is complete at almost 10 hours. There is a brief pause where the screen goes black after one full rotation. As the planet rotates, the radiation belts appear to (1) tip to the left, (2) tip toward the viewer, (3) tip to the right and then (4) tip away from the viewer. When the radiation belts are to the left or the right, we receive the maximum signal from Jupiter (images sets 3 and 7 in the student pages). When the belts are tilted toward or away the field of view, we receive a lower signal (image set 1, 2, 4, 5, 6, and 8). The minimum signal images sets are 1 and 5. Students can see the right-to-left tipping by comparing images in sequence and infer the toward-and-away tilting by looking at the changing radio brightness in the graph. Have students look at the false color image of the synchrotron filed in relation to the white line that represents Jupiter's equatorial plane in each image set.



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Please Note: The still images reflect nine of the almost ten hours of Jupiter's rotation. Students may ask why the false color images are sometimes very asymmetric and why they appear to change erratically with rotation. The answer is that Jupiter's magnetic field is not uniform. There are specific locations in the magnetic field where the field lines are twisted or "kinked", making the shape of the magnetic field very complex and producing localized distortions in the synchrotron emission maps. Scientists are currently studying this phenomenon to better understand the Jovian magnetosphere.

Vocabulary

Flux density Flux density is the amount of energy in a given area per unit of time. In this case we are referring to the amount of synchrotron radiation energy in Jansky units

Radio

Brightness This is another way of describing the synchrotron radiation intensity. This is how bright a source appears in the radio spectrum, and is measured in Kelvins for this exercise (It can be expressed in other units of measurement.).

Synchrotron

Emission Non-thermal energy that is released from charged particles when those charged particles are caught in a magnetic field, moving at almost the speed of light. As the charged particles move along the magnetic field lines, they circle around the lines at almost the speed of light, releasing energy in the form of radio waves called synchrotron radiation

Very

Large

Array

The Very Large Array (VLA) is an astronomical radio observatory operated by the National Radio Astronomy Observatory (NRAO) in Socorro, New Mexico. The VLA is made up of 27 radio antennae, each one 25 meters in diameter, configured in a Y-shaped pattern. When these antennae are combined electronically, the structure gives a resolution equal to an antenna up to 36 kilometers in diameter. More information on the VLA can be obtained at the following address:

<http://info.aoc.nrao.edu/vla/html/VLAintro.shtml>

References:

Kaufman, W.J. (1996). Universe (4th ed.). W.H. Freeman and Company: New York.

Jet Propulsion Laboratory. (1998). Basics of Radio Astronomy, April 1998 (JPL D-13835). Pasadena, California: Author.



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PHOTO:NASA/NOAA

Student Part One: Earth's Rotation

Beginning at 0° latitude and 32° East longitude (Northwestern edge of Lake Victoria on the continent of Africa), record what you see by circling **land** or **water** every 45° of longitude. Hint: If you are using the movie animation, take a reading every second by pausing the video.

Position One:	Land	Water	at 0° latitude and 32° East longitude
Position Two:	Land	Water	
Position Three:	Land	Water	
Position Four:	Land	Water	
Position Five:	Land	Water	
Position Six:	Land	Water	
Position Seven:	Land	Water	
Position Eight:	Land	Water	
Position Nine:	Land	Water	
Position Ten:	Land	Water	
Position Eleven:	Land	Water	
Position Twelve:	Land	Water	
Position Thirteen:	Land	Water	
Position Fourteen:	Land	Water	
Position Fifteen:	Land	Water	
Position Sixteen:	Land	Water	



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Student Questions:

1. What do you notice about your record after position eight?
2. Try the activity again at another latitude. Do you see a pattern emerging? Describe it.

For more information on Earth's rotation select the following links:

http://windows.arc.nasa.gov/cgi-bin/tour_def/the_universe/uts/earth2.html

A page from *Windows to the Universe*, copyrighted by The Regents of the University of Michigan

<http://image.gsfc.nasa.gov/poetry/ask/arot.html>

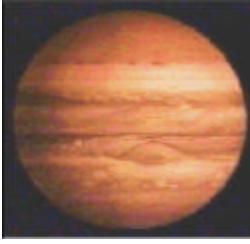
FAQ on Earth's Rotation

All answers are provided by Dr. Sten Odenwald (Raytheon STX) for the NASA IMAGE/POETRY Education and Public Outreach program.



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Student Part Two: Jupiter's Rotation

PHOTO:

NASA/JPL

Watch the Jupiter rotation movie. Answer the following questions based on your visual observations.

Student Questions:

1. What features can you identify as evidence that Jupiter is rotating?
2. Select a feature and determine how long one full rotation of Jupiter takes in hours. For the first part of the video, one second on the video is actually one hour in real time.
3. Do all the features that you see appear to be rotating at the same rate? Explain your answer.

For more information on Jupiter:

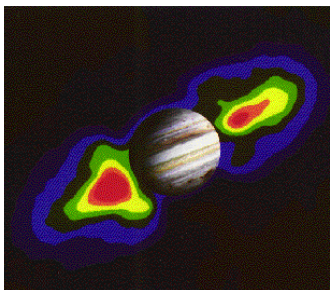
<http://www.jpl.nasa.gov/galileo/jupiter/jupiter.html>

Galileo Project: Jupiter



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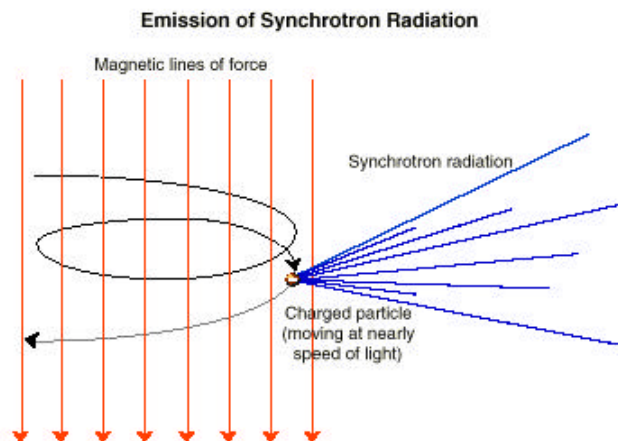


Student Part Three: Jupiter's Rotation and Synchrotron Emission

Watch the movie showing Jupiter's synchrotron emission.

Background Information:

Jupiter's magnetosphere is very large. If the magnetosphere of Jupiter could be seen from Earth, "it would cover an area in the sky sixteen times larger than the full moon" (Kaufmann, 1996). When charged particles are trapped within a magnetic field like the one surrounding Jupiter, they move around the magnetic lines of force in a path with the shape of a helix, rapidly circling the field lines as they move along them. In Jupiter's magnetosphere, many of these particles are moving very fast, near the speed of light. This helical motion of rapidly moving charged particles causes them to emit energy in the form of radio waves called [synchrotron radiation](#) (see illustration below).



Collectively, the particles form belts around the planet, much like the Van Allen radiation belts around Earth. (Note that the "radiation" in "radiation belts" consists of subatomic particles, while the "radiation" in "synchrotron radiation" consists of radio waves.)



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Jupiter's radiation belts resemble a donut (toroidal) shape that surrounds the planet (see image below). The synchrotron radiation they produce is, by definition, non-thermal, meaning that it is not created by processes related to heat and temperature.

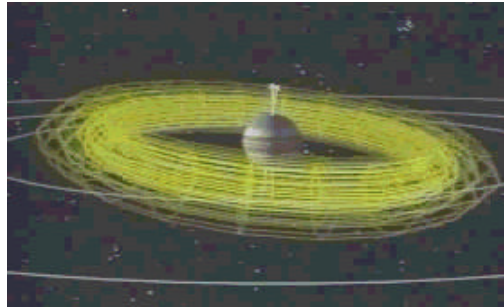


Image from NASA movie
Magnetic Field of Jupiter,
based on Voyager data,
reference CMP 346

The false color image you see in the video on either side of Jupiter represents the strength of the synchrotron emission (or the radio brightness) at the time the observation was made with the [Very Large Array](#) (VLA) collection of radio telescopes. Since the synchrotron radiation is produced by the particles in the radiation belt, the view resembles a cross-section of the belts, as if you had cut the donut in half and set the planet in the middle.

Jupiter's rotational axis and its magnetic pole are offset from one another by about ten degrees (this occurs for Earth also, and the offset is between 11 and 12 degrees), causing a wobble in the radiation belts as the magnetosphere rotates. As Jupiter's wobbling magnetic field, carrying the radiation belts with it, faces more toward Earth and then away from Earth in its rotation (somewhat like a plate spinning on a tabletop), the [radio brightness](#) of the [synchrotron emission](#) appears to brighten and dim.

Using the spinning plate analogy, when the plate is near the end of its spin, you can see it edge-on and then surface of the plate as an elongated oval, then the edge-on again etceteras. Jupiter's radiation belts present this changing aspect with each ~ ten hour rotation. This occurs because the synchrotron radiation produced by each particle is emitted mostly in the direction that the particle is moving, like headlights on a car. As the particles circle around the field lines, they emit much more radiation perpendicular to the field lines than they do along the lines. Picture a small car with its lights on driving around the edge of the wobbling plate. You would see the most light when the car is driving toward you at the right or left edges of the plate. As Jupiter's rotation wobbles the magnetic field around, the total radiation we see from all the particles varies, getting brighter when we're looking at the field from the side (perpendicular) and getting dimmer when the field is tilting toward us or away from us. When the tilt is to the left or right, a lot of the "headlights" are aimed at us (like the edge-on plate), and when the field is tilted toward (or away) from us, most of the "headlights" are aimed too low (or too high) for us to see them as well (like the elongated oval plate).



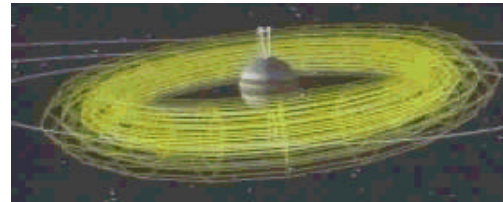
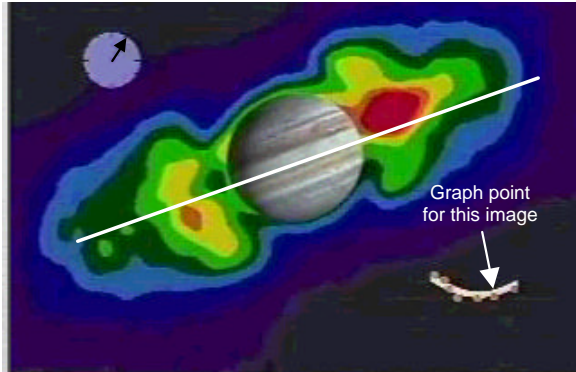
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Student Reflection and Questions:

Watch the synchrotron rotation movie again. The images below on the left are from the movie. The picture to the right of the first animation image will help you visualize what is happening. Remember that the radiation belts tip left, then toward you, then to the right and then away from you. The white line on each image represents the equatorial plane of the visible image of Jupiter. Watch to see where the false color image of the synchrotron radiation is in relationship to the equatorial line on each image.

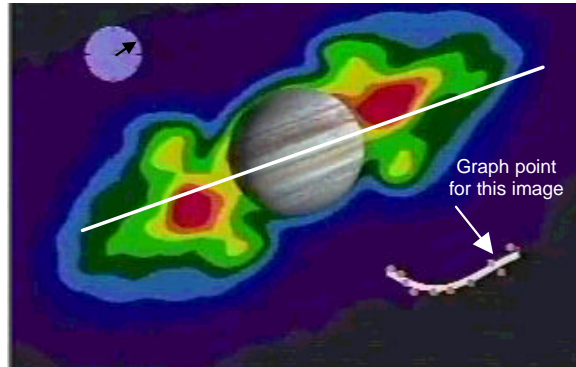
IMAGE SET 1



This is the beginning of the animation. Describe the tilt of the radiation belts.

Is the synchrotron radiation at its brightest or dimmest? How can you tell?

IMAGE SET 2



How many hours have passed in the Jupiter rotation in Image Set 2? Describe the orientation of the radiation belts.

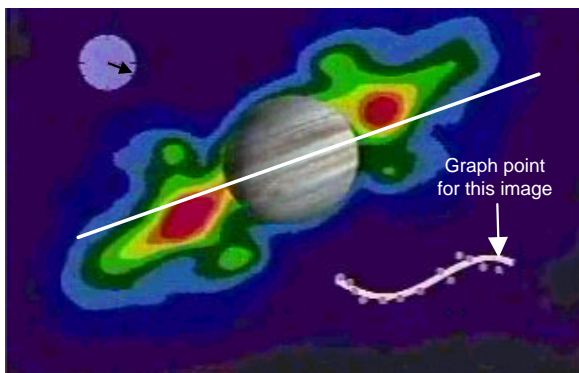
Is the synchrotron radiation at its brightest or dimmest? How can you tell?



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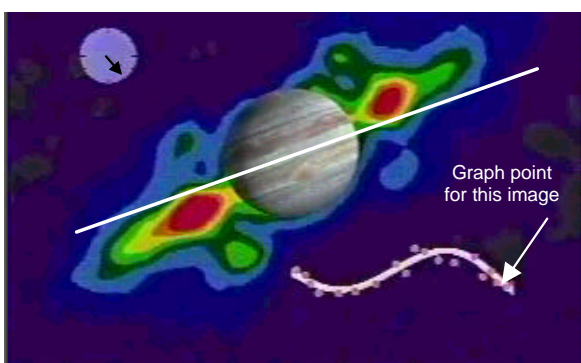
IMAGE SET 3



How many hours have passed in the Jupiter rotation in Image Set 3? Describe the orientation of the radiation belts.

Is the synchrotron radiation at its brightest or dimmest? How can you tell?

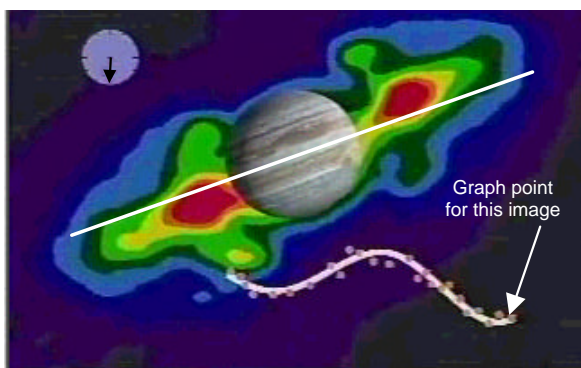
IMAGE SET 4



How many hours have passed in the Jupiter rotation in Image Set 4? Describe the orientation of the radiation belts.

Is the synchrotron radiation at its brightest or dimmest? How can you tell?

IMAGE SET 5



How many hours have passed in the Jupiter rotation in Image Set 5? Describe the orientation of the radiation belts.

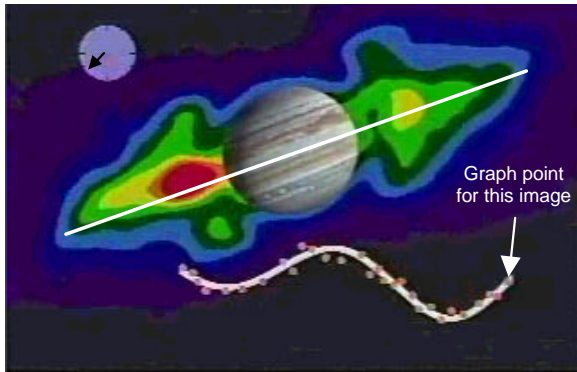
Is the synchrotron radiation at its brightest or dimmest? How can you tell?



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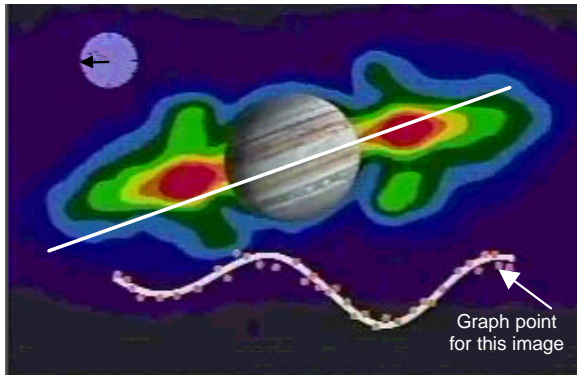
IMAGE SET 6



How many hours have passed in the Jupiter rotation in Image Set 6? Describe the orientation of the radiation belts.

Is the synchrotron radiation at its brightest or dimmest? How can you tell?

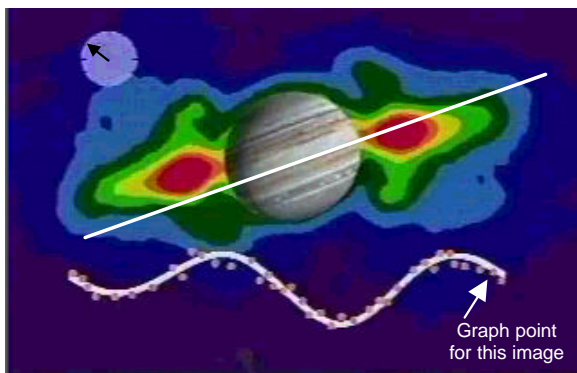
IMAGE SET 7



How many hours have passed in the Jupiter rotation in Image Set 7? Describe the orientation of the radiation belts.

Is the synchrotron radiation at its brightest or dimmest? How can you tell?

IMAGE SET 8



How many hours have passed in the Jupiter rotation in Image Set 8? Describe the orientation of the radiation belts.

Is the synchrotron radiation at its brightest or dimmest? How can you tell?



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As Jupiter's magnetic pole alternately tilts toward Earth and then away, so do the radiation belts, and the synchrotron emission (flux density) data points increase and decrease (measured in Jansky units). The synchrotron emission strength doesn't really change this much over the rotational period of Jupiter. What else might be happening?

Explore the following questions to figure it out.

1. Think of our antenna beam as a funnel that catches energy that comes to it. Are we catching all the energy that is being emitted?
2. If Jupiter's radiation belts are wobbling (due to its magnetic pole tilting toward Earth and then away), is the energy going out in a constant direction? What causes the change in signal strength during rotation?
3. Look at the movie and pages 12 – 13 again. How does the graph at the bottom of the movie coincide with the planet's motion?
4. What is the planet doing when the synchrotron radiation energy is at its greatest? At a minimum?
5. What is happening with our "funnel" scenario when the planet wobbles? Are we catching the same amount of energy throughout the rotation period of Jupiter? Why or why not?

For more information on Jupiter's magnetosphere:

<http://space.rice.edu/hmns/dlt/Jupmag.html>

Jupiter's Magnetosphere: The Biggest Thing in the Solar System

<http://csep10.phys.utk.edu/astr161/lect/jupiter/magnetic.html>

The Magnetic Field of Jupiter

http://windows.arc.nasa.gov/cgi-bin/tour_def/jupiter/magnetosphere/J_mag_topology_overview.html

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Mid-Continent Research for Education and Learning (McREL) Science Education Standards:

<http://www.mcrel.org/standards-benchmarks/>

1. Understands basic features of the Earth

Level II: Upper Elementary

- Knows that night and day are caused by the Earth's rotation on its axis

3. Understands essential ideas about the composition and structure of the universe and the Earth's place in it

Level II: Upper Elementary

- Knows that telescope magnify distant objects in the sky and dramatically increase the number of stars we see

Level IV: High School

- Knows ways in which technology has increased our understanding of the universe (e.g. visual, radio, and x-ray telescopes collect information about the universe from electromagnetic waves; computers interpret vast amounts of data from space; space probes gather information from distant parts of the Solar System; accelerators allow us to simulate conditions in the stars and in the early history of the universe)

14. Understands the nature of scientific knowledge

Level II: Upper Elementary

- Knows that although the same scientific investigation may give slightly different results when it is carried out by different persons, or at different times or places, the general evidence collected from the investigation should be replicable by others

Level III: Middle School/Junior High School

- Knows that an experiment must be repeated many times and yield consistent results before the results are accepted as correct

Level IV: High School

- Knows that scientific explanations must meet certain criteria to be considered valid (e.g., they must be consistent with experimental and observational evidence about nature, make accurate predictions about systems being studied, be logical, respect the rules of evidence, be open to criticism, report methods and procedures, make a commitment to making knowledge public)

15. Understands the nature of scientific inquiry

Level II: Upper Elementary

- Knows that scientific investigations involve asking and answering a question and comparing the answer to what scientists already know about the world
- Knows that scientists use different kinds of investigations (e.g., naturalistic observation of things or events, data collection, controlled experiments), depending on the questions they are trying to answer
- Knows that good scientific explanations are based on evidence (observations) and scientific knowledge
- Knows that different people may interpret the same set of observations differently

Level III: Middle School/Junior High School

- Knows that there is no fixed procedure called "the scientific method," but that investigations involve systematic observations, carefully collected, relevant evidence, logical reasoning, and some imagination in developing hypotheses and explanations



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- Establishes relationships based on evidence and logical argument (e.g., provides causes for effects)
- Understands the nature of scientific explanations (e.g., emphasis on evidence; use of logically consistent arguments; use of scientific principles, models, and theories; acceptance or displacement based on new scientific evidence)
- Knows that scientific inquiry includes evaluating results of scientific investigations, experiments, observations, theoretical and mathematical models, and explanations proposed by other scientists (e.g., reviewing experimental procedures, examining evidence, identifying faulty reasoning, identifying statements that go beyond the evidence, suggesting alternative explanations)

Level IV: High School

- Understands the use of hypotheses in science (e.g., selecting and narrowing the focus of data, determining additional data to be gathered; guiding the interpretation of data)
- Knows that a wide range of natural occurrences may be observed to discern patterns when conditions of an investigation cannot be controlled
- Uses technology (e.g., hand tools, measuring instruments, calculators, computers) and mathematics (e.g., measurement, formulas, charts, graphs) to perform accurate scientific investigations and communications
- Knows that scientists conduct investigations for a variety of reasons (e.g., to discover new aspects of the natural world, to explain recently observed phenomena, to test the conclusions of prior investigations, to test the predictions of current theories)

16. Understands the nature of scientific enterprise

Level II: Upper Elementary

- Knows that although people using scientific inquiry have learned much about the objects, events, and phenomena in nature, science is an ongoing process and will never be finished
- Knows that scientists and engineers often work in teams to accomplish a task

Level III: Middle School/Junior High School

- Knows that the work of science requires a variety of human abilities, qualities, and habits of mind (e.g., reasoning, insight, energy, skill, creativity, intellectual honesty, tolerance of ambiguity, skepticism, openness to new ideas)
- Knows various settings in which scientists and engineers may work (e.g., colleges and universities, businesses and industries, research institutes, government agencies)

Level IV: High School

- Understands that individuals and teams contribute to science and engineering at different levels of complexity (e.g., an individual may conduct basic field studies; hundreds of people may work together on a major scientific question or technological problem)
- Understands that science involves different types of work in many different disciplines (e.g., scientists in different disciplines ask different questions, use different methods of investigation, and accept different types of evidence to support their explanations; many scientific investigations require the contributions of individuals from different disciplines; new disciplines of science, such as geophysics and biochemistry, often emerge at the interface of older disciplines)



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